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The Compact Muon Solenoid Experiment

Analysis Note

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Determination of Pb-Pb Event Centrality Using CASTOR and HF Calorimeters in CMS

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Abstract

The Compact Muon Solenoid (CMS) experiment at the LHC is a general purpose detector designed to investigate the physics at the TeV scale. Although the main goal of the CMS experiment is the search of new physics phenomena (Higgs boson, beyond Standard Model signals, etc), the HF and CASTOR calorimeters provide CMS with a large calorimetric coverage in the forward direction, which provides excellent detector capabilities for heavy-ion studies. The measurement of the impact parameter, b, or centrality of a heavy ion collision is essential to characterize the events, because many phenomena in heavy-ion collisions depend crucially on the amount of overlap between the colliding ions. The monotonic correlation between the transverse energy deposited in the forward detectors and b makes possible a measurement of the impact parameter with a resolution of about 1 fm. We will present generator-level studies of the capabilities of the HF and CASTOR calorimeters to determine the centrality of the events in Pb-Pb collisions at squares = 5.5 TeV collisions, in CMS.

1 Introduction

Large Hadron collider (LHC) will present a great opportunity for heavy ion studies. Center-of-mass energy at LHC for heavy ion collisions is almost 30 times higher than the maximum energy available at RHIC. Reaching these higher energies will contribute greatly to understand the properties of QCD matter. These higher enegies also give rise to larger lifetimes of the quark-gluon plasma and larger freeze out volume and temperature. Therefore, a large fraction of the system lifetime is spent in a purely partonic state and it allows more detailed study which is not possible at the lower energies [1].
There will be four experiments located at the four collisions points of LHC. CMS[2] and ATLAS are multi-purpose detectors, designed to study a large domain of physics. ALICE is dedicated to heavy ion physics and LHCb especially designed for b-physics.
The CMS detector has a cylindrical shape with symmetry in the azimuthal angle. The detector is built with 21.6 m length, 14.6 m diameter and 14500 tons of weight. The CMS has a 4π solid angle coverage and there are 4 main subsytems that are tracker, calorimeters, magnet and muon system. The magnet system provides 4T magnetic field which is parallel to the beam direction. The tracker covers the pseudorapidity region $|\eta| < 2.5$ and uses silicon technology. The ECAL is composed of barrel and end-cap parts and includes almost 76 000 $PbWO_4$ (lead-tungstenate) crystals. The barrel part covers $|\eta| < 1.48$ and end-cap part covers up to $|\eta| < 3$. The hadronic calorimeter consists of barrel and end-cap sections and it is composed of copper plate and plastic scintillator sandwich. The pseudoudorapidity range of $|\eta| < 3$ is covered by barrel and end-caps part. The muon system covers $|\eta| < 2.4$. Althoug the main goal of CMS is to search electroweak symmetry breaking and new physics phenomena at p-p collisions, CMS has a large forward coverage and good energy resolution with HF $(3 < |\eta| < 5)$, CASTOR $(5.3 < |\eta| < 6.7)$ and ZDC $(|\eta| > 8)$. This large coverage for tracking and calorimeters, large granularity and resolution make the CMS an ideal detector for heavy ion studies. [3]

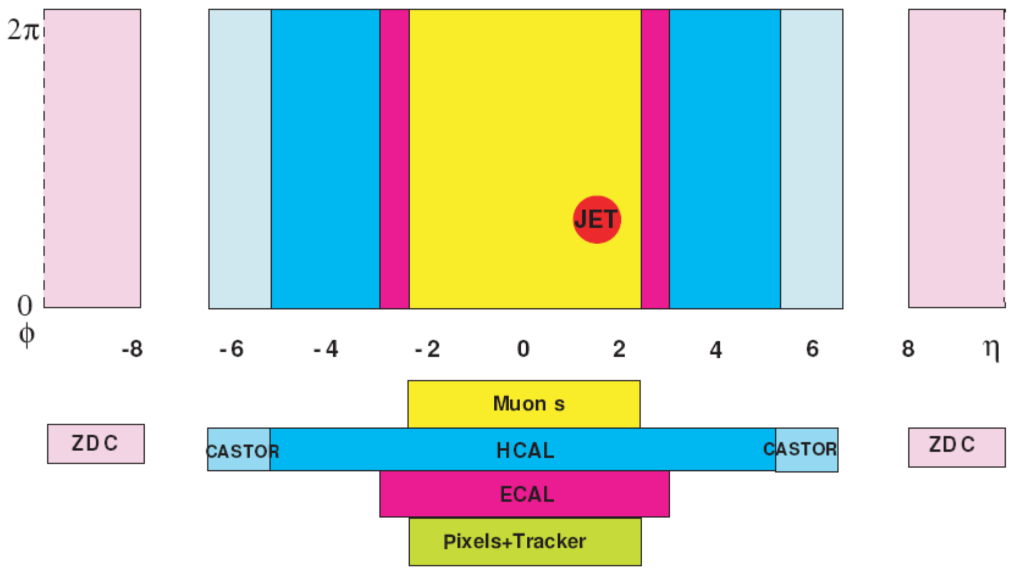

Figure 1: CMS acceptance of tracking, calorimetry and muon identification in pseudo-rapidity (η) and azimuth (φ). The size of a jet with cone radius $R = 0.5$ is also depicted for illustration.

HF[4] (Hadronic Forward) calorimeter is a hadronic calorimeter and is located 11 m away from the collision point. HF consists of iron absorber, quartz fibers embedded into the absorber. There are two HF calorimeters, one at each end of CMS. HF provides missing transverse energy measurements and jet identification and reconstruction. CASTOR[5] (Centauro And STrange Object Research) is a quartz-tungsten sampling Čerenkov calorimeter and consists of electromagnetic and hadronic sections. CASTOR is located 16.4 m away from the collision point. The ZDC (Zero Degree Calorimeter) is able to measure neutrons and photons at 0 degrees. The pseudorapidity region covered by HF and CASTOR is important in heavy ion collisions can be seen from Figure 2.

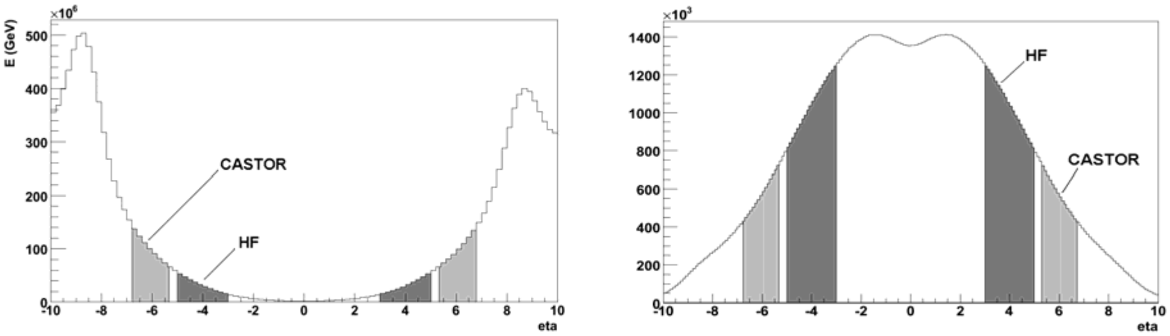

Figure 2: The distribution of number of particles (right) and energy (left) distribution over pseudorapidity in Pb-Pb collision.

Figure 2 shows the final state particles distribution (left) and their energy distribution (right) over pseudorapidity in Pb-Pb collision at $\sqrt{s} = 5.5\,\mathrm{TeV}$. The pseudorapidity region covered by HF and CASTOR is shown with different colors in the histograms. Although, there are relatively less particles in the pseudorapidity regions of HF and CASTOR, they carry a large fraction of the total energy flow.

2 Centrality Measurement in Pb-Pb collisions using HF and CASTOR

The physics programme of CMS includes many aspects of heavy ion physics such as event-by-event charged multiplicity and and energy flow measurement[6], production of quarkonia and heavy quarks[7], elliptic flow, high $-p_T$ particles and jets[6]. In the beggining of LHC, the luminosity will be lower than expected. Therefore in the first runnings at this low-luminosity, measurements in heavy ion collisions will focus on soft physics and global event characterization as a function of centrality. Centrality of an event or impact parameter (b) is defined as the distance between colliding two nuclei. If impact parameter is small, the event is called central collision. If impact parameter is large, the event is called peripheral collision. Measurement impact parameter or centrality of an event is extremely important for event characterisation. Centrality of a heavy ion event can not be measured direcly. It can be only derived from measured variables. The event centrality of a high energy heavy ion collision is determined by measuring i) total charged particle multiplicty, N_c, ii) transverse energy flow in various pseudorapidity regions[3]. These observable variables increase significantly with incresing centrality of collisions. In this study, transverse energy (E_T) and energy flow-impact parameter and HF response– impact parameter correlation are examined at generator level.
Almost 10000 unquenched minbias events generated with HYDJET[8] (HYDJET1.2) event generator was used for this study. All analysis was made using CMSSW[9] (CMSSW_1_5_1) framework.
Total energy and total transverse energy flow of final states particles in the pseudorapidity regions of HF and CASTOR for various impact parameters are illustrated in Figure 3.

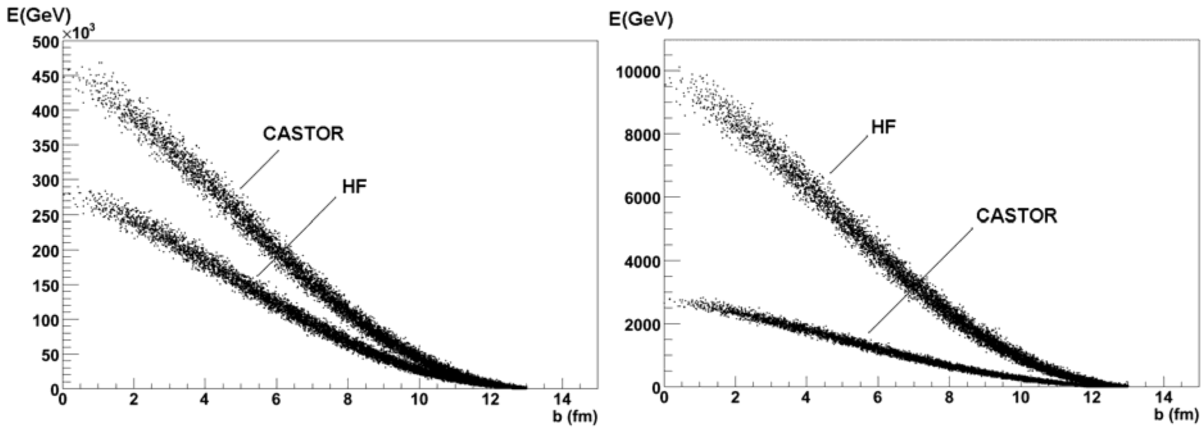

Figure 3: Energy (left) and transverse energy (right) flow in HF and CASTOR pseudorapidity for various impact parameters.

Energy and transverse energy flow decrease significantly when impact parameters increase. The correlation between total energy and the impact parameters has a similar form to transverse energy – impact parameter correlation. Although total energy flow in CASTOR is larger than in HF, the situation is opposite for transverse energy flow. Because CASTOR covers larger η region than HF, the polar angle for CASTOR region is smaller than that for HF region and transverse energy flow ($E_T = E\sin\theta$) in CASTOR region is lower than the one in HF region. The same study with HIJING event generator and HIROOT framework can be found in [4].
There are two HF and two CASTOR calorimeters which are located one at each end of CMS. One of them covers the pozitif η region and the other covers the negatif η region. The histograms in Figure 4 denote the E_T flow correlation between pozitif and negatif pseudorapidity regions of HF and CASTOR calorimeters for final state particles.

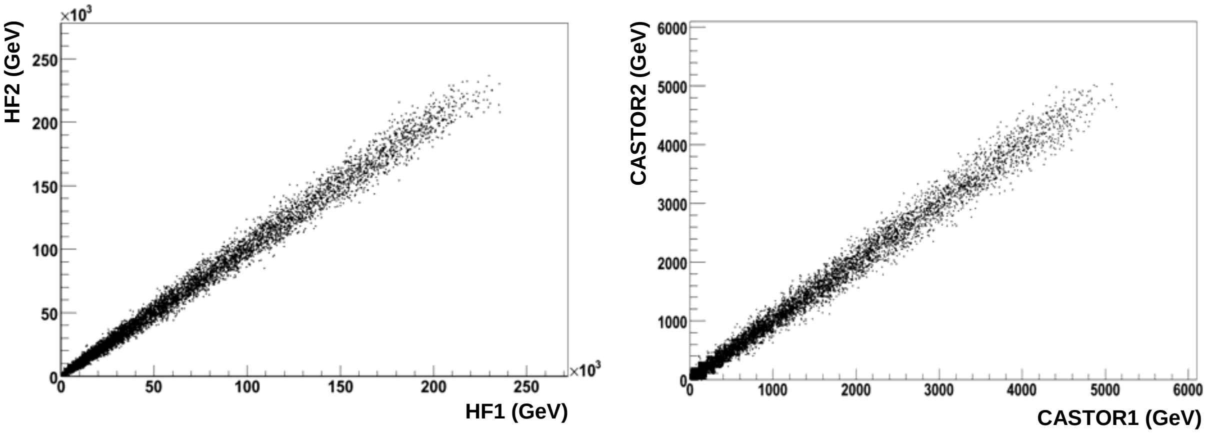

Figure 4: The E_T flow correlation between pozitive and negative pseudorapidity regions for HF and the energy flow correlation between pozitive and negative pseudorapidity regions for CASTOR.

HF1 $(3 < \eta < 5)$ and CASTOR1 $(5.3 < \eta < 6.7)$ are for pozitive η, HF2 $(-3 > \eta > -5)$ and CASTOR2 $(-5.3 > \eta > -6.7)$ are for negative η regions. There is good correlation between two sides for total E_T flow for HF. Since CASTOR covers the small angles 0.2˚-0.6˚ in CMS, measuring transverse energy flow in CASTOR is not realistic. There is also good correlation between two sides for energy flow for CASTOR can be seen in Figure 4.
HF with iron absorber absorbs a large fraction of total energy flow. HF response or energy deposition values in HF for various impact parameters is shown in Figure 5. There is the same shape in Figure3. Almost 75% of total energy flow is absorbed by HF. When energy flow increases, HF response also increases proportional with the energy flow. There is excellent correlation between generated and reconstructed level as illustrated in Figure 5.

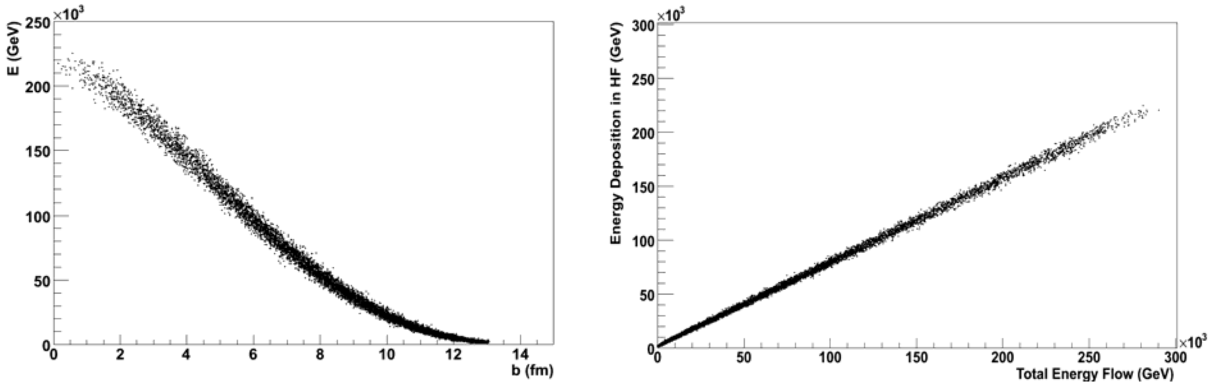

Figure 5: Energy deposition in HF for various impact parameters (left) and the correlation between energy flow and energy deposition in HF (right).

Because of existing excellent correlation between energy deposition in HF and energy flow, impact parameter can be determined using energy deposition in HF with a resolution less than 1 fm. The histograms in Figure 6 show the impact parameter distributions at some fixed values of energy deposition in HF. When an impact parameter distribution is fited to a gaussian, σ_b value gives the impact parameter resolution. The impact parameter resolution using fixed energy deposition values in HF and fixed energy flow values in CASTOR are given in Figure 7. All fixed values ranges almost include the same number of entries. The estimated resolution σ_b is about 0.5 fm.

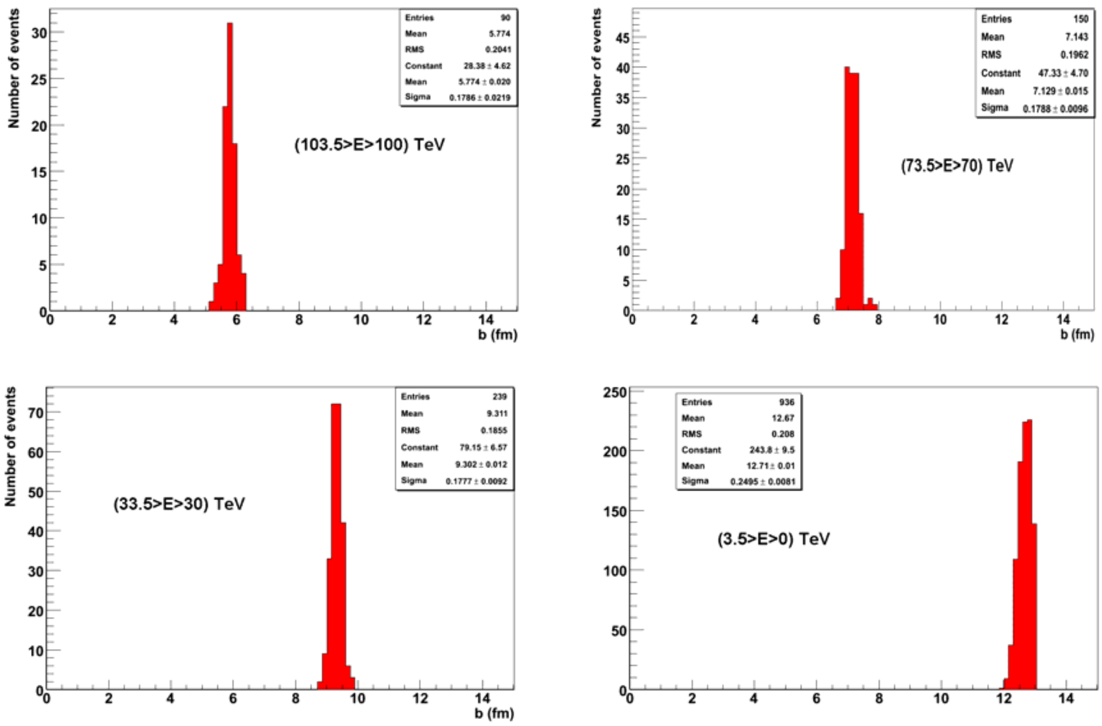

Figure 6: The distributions of impact parameter at fixed energy deposition values in HF.

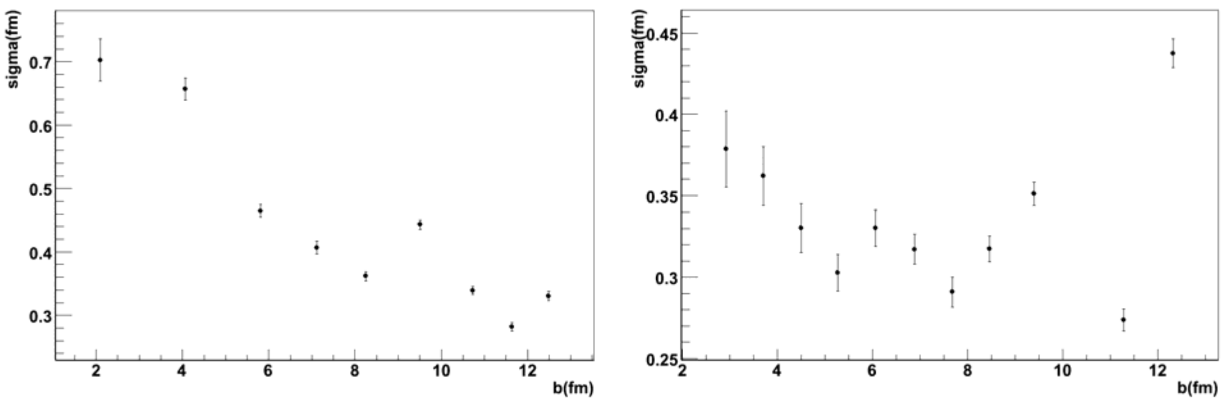

Figure 7: The impact parameter resolutions using energy deposition in HF (left) and energy flow in CASTOR (right).

3 Summary

Global observables in a heavy ion collision (Pb-Pb) are strongly related with the centrality of the event. By combining informations from some measurements like energy and E_T flow in HF and CASTOR and energy deposition in HF, and also forward energy flow of the neutral particles in ZDCs, we can clearly determine the impact parameter of a heavy ion collision with a resolution less than 1 fm in CMS. Using HF and CASTOR calorimeters in CMS is a good tool to determine Pb-Pb event centrality and event characterization.

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